FINAL
Summary Report
Time Schedule Order R9-2002-0042

Mission Valley Terminal
9950 and 9966 San Diego Mission Road
San Diego, California

January 30, 2004
002-10180-13

Prepared for
SFPP, L.P., an Operating Partner of
Kinder Morgan Energy Partners, L.P.
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January 30, 2004

002-10180-13

Ms. Kelly Dorsey
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Subject: Final Summary Report, Time Schedule Order R9-2002-0042
Mission Valley Terminal
9950 and 9966 San Diego Mission Road
San Diego, California

Dear Ms. Dorsey:

LFR Levine·Fricke (LFR) has prepared the enclosed report on behalf of SFPP, L.P., an operating partner of Kinder Morgan Energy Partners, L.P. The Summary Report has been completed in fulfillment of Task D of Time Schedule Order (TSO) R9-2002-0042, adopted by the San Diego Regional Water Quality Control Board (RWQCB) on March 13, 2002. Submittal of this report to the RWQCB fulfills the final requirement of TSO R9-2002-0042.

If you have questions regarding the material presented in this report, please contact either of the undersigned at (714) 444-0111.

Sincerely,

Scott E. Martin, R.G.
Senior Associate Hydrogeologist

Jennifer A. Rothman
for Eric M. Nichols, P.E.
Principal Engineer and Vice President

Enclosure

cc: Mr. K. Ryan, KMEP
Mr. T. Olson, City of San Diego
Mr. D. Johnson, City of San Diego
Mr. M. Barranco, CENCO-Powerine Oil Co.
Mr. S. Pao, ExxonMobil Oil Corp.
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CERTIFICATION

All hydrogeologic and geologic information, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by an LFR Levine·Fricke California Registered Geologist.

1/30/04

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All engineering information, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by an LFR Levine·Fricke California Professional Engineer.

1/28/04

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1.0 INTRODUCTION

LFR Levine·Fricke (LFR) has prepared this report on behalf of SFPP, L.P., an operating partner of Kinder Morgan Energy Partners, L.P. (Kinder Morgan) regarding the remedial activities related to the Mission Valley Terminal, located at 9950 and 9966 San Diego Mission Road, San Diego, California (Figures 1 and 2). This Summary Report has been completed in fulfillment of Task D of Time Schedule Order (TSO) R9-2002-0042, adopted by the California Regional Water Quality Control Board, San Diego Region (RWQCB) on March 13, 2002 (CRWQCBSDR 2002). Submittal of this document fulfills the final requirement of TSO R9-2002-0042.

The objective of this document is to present the following:

- results of the numerical groundwater flow and contaminant transport model including an updated evaluation of methyl tertiary-butyl ether (MTBE) mass flux estimates
- a summary of the previously completed performance evaluation activities for the expanded soil-vapor and groundwater extraction systems along with additional recommendations for continuing optimization of the expanded systems
- a summary of Health Risk Assessment activities relating to both the off-site and on-site areas
- an update to the Conceptual Risk Management Plan originally presented in the Health Risk Assessment for Off-Site Areas dated August 11, 2003 (referred to as a "contingency plan" in the TSO)
- proposed milestone cleanup dates for the restoration of water quality in the portion of the Mission San Diego Hydrologic sub-area proposed for development by the City of San Diego for municipal use and for the clean up of all off-site pollution

2.0 MTBE MASS FLUX ESTIMATES

2.1 Mass Flux Report and Addendum to the Mass Flux Report

Empirical estimates of the mass flux of MTBE in the off-site groundwater were used to evaluate impacts to potential future groundwater and surface water receptors off-site and to investigate off-site MTBE plume attenuation. The Mass Flux Report (LFR 2003b) was completed in fulfillment of Task B.2 of the TSO, and was submitted to the RWQCB on June 6, 2003. An Addendum to the Mass Flux Report (LFR 2003d) that included updated and additional historical off-site MTBE mass flux estimates was submitted to the RWQCB on November 20, 2003. The specific objectives of the off-site mass flux evaluation were to:

- estimate the mass discharge (total mass flux) of MTBE in groundwater at selected off-site locations (transects) over time

- estimate impacts to potential groundwater and surface water receptors that may be exposed to MTBE in off-site groundwater, including a future water supply well, recreational users of the San Diego River (adult and child), and sensitive ecological receptors in or near the San Diego River
- investigate the potential attenuation of the MTBE plume
- estimate the total volume of groundwater impacted by MTBE in the off-site area

MTBE mass flux was calculated at three locations within the off-site MTBE plume. The first location is the line of extraction wells RW-3A through RW-7, and was calculated with system influent and analytical data for December 2001 through August 2003, and represents a mass removal rate. The other two locations are monitoring well transects located downgradient of the Stadium across the plume width. Calculation of mass flux at monitoring well transects is referred to as the Transect Method, and uses estimates of groundwater discharge and analytical data samples collected from the monitoring well clusters located across each transect for May 2001 through May 2003. For a complete description of the transects, details regarding the data and methods used to estimate mass flux and impacts to potential future receptors, and discussion of the results of the evaluation, refer to the Mass Flux Report (LFR 2003b) and the Addendum to the Mass Flux Report (LFR 2003d).

Results of the MTBE mass flux evaluation, as presented in the Addendum Report, indicated the mass removal rates for the extraction system generally decreased over time, and ranged from a maximum of 876 grams per day (g/d) in January 2002 to a minimum of 93 g/d in July 2002. The most recent mass removal that was calculated (May 2003) was 125 g/d, which represents a six-fold decrease since December 2001.

As presented in the Addendum Report, the mass flux at Transect 1 ranges from a high of 230 g/d in November 2001, and decreases by two orders of magnitude over time to approximately 3 g/day in May 2003. The mass flux at Transect 2 ranges from a high of 89 g/d in November 2001 and continues to generally decrease over time to 0.6 g/day in May 2003.

The Mass Flux Report and Addendum identified several lines of evidence indicating that the off-site MTBE plume is attenuating. Both the mass of MTBE and volume of affected groundwater above detectable concentrations (>1 microgram per liter [µg/l]) within the dissolved off-site plume between the November 2002 and February 2003 monitoring events decreased, with a 53 percent decrease in mass and a 6 percent decrease in affected volume. The decreases in the mass flux between transects and at a given transect location, a general decreasing trend in MTBE concentrations at monitoring wells throughout the off-site plume, and the decrease in the overall downgradient extent and concentrations of the plume also support conclusions regarding plume attenuation. Significant reductions in MTBE concentrations observed in wells near the extraction system, as well as in the width and downgradient extent of the maximum concentrations within the core of the MTBE plume, suggest that contamination upgradient of the groundwater extraction system is being successfully contained.

Applicable water quality objectives for groundwater for a future water supply well receptor would include California primary and secondary MCLs for MTBE (13 and 5 µg/l, respectively). In the Mass Flux Report, the February 2003 empirical mass flux estimates at Transects 1 and 2 were used to estimate MTBE concentrations in a future hypothetical supply well and the San Diego River. These mass fluxes result in potential wellhead concentrations of approximately 0.3 to 3.7 µg/l for typical supply well pumping rates based on estimated well yields for the Mission San Diego Basin, with the maximum well yields based on preliminary results of numerical modeling (up to 200 gallons per minute [gpm] possible without induced flow from the San Diego River).

Potential concentrations in the San Diego River were much lower than those associated with the hypothetical future supply well, and ranged from 0.00003 to 0.11 µg/l. These concentrations are much lower than the applicable standards for surface water. Nationwide studies of MTBE occurrence in air, groundwater, and surface water have shown that concentrations of MTBE in groundwater and surface water of less than 30 µg/l may be attributable to non-point sources, such as atmospheric washout or water interaction with contaminated road surfaces.

In the Addendum to the Mass Flux Report, additional information regarding pumping rates for a potential future supply well was obtained from the City of San Diego Reservoir Management Study (Boyle Engineering 1995; “the water management study”). For the Mission San Diego Basin, the water management study concluded that the most economically feasible alternative suggested eight groundwater supply wells would be used to extract this groundwater from the basin, which results in 188 gpm per well, if pumping is distributed evenly among eight wells. The most recent mass flux at the downgradient edge of the plume (Transect 2; May 2003) was used to calculate the wellhead concentration of MTBE for a hypothetical future water supply well. This transect is closest to the San Diego River, where the transmissivity of the alluvial material is highest and where a water supply well would likely be located. To be conservative, it was assumed that the capture zone for the hypothetical well included the entire width of the plume of MTBE-affected groundwater. The total MTBE mass flux calculated in May 2003 at Transect 2 (0.6 g/d) and an assumed supply well pumping rate of 188 gpm results in a wellhead concentration of approximately 0.6 µg/l, which is well below the relevant primary and secondary criteria for MTBE.

2.2 Property Boundary Mass Flux Report

Mass flux was estimated with the Transect Method at a monitoring well transect located at the Terminal property boundary in support of site containment and remediation strategies, and to further investigate the effectiveness of the off-site groundwater extraction system. The Property Boundary Mass Flux Report (LFR 2004a) was submitted to the RWQCB on January 12, 2004. MTBE and benzene mass flux at the property boundary were calculated for 20 monitoring events from June 1996 through August 2003, and tertiary butyl alcohol (TBA) mass flux at the property boundary was calculated for 8 monitoring events from August 2001 through August 2003. In addition, the extraction system mass removal for these three constituents was calculated (updated for MTBE).

Groundwater at the property boundary and other on-site areas is in contact with residual light nonaqueous phase liquid (LNAPL), which was accounted for in the mass flux calculations by assigning equivalent source term concentrations for MTBE and benzene. These values were based on the maximum weight percent of each constituent in LNAPL samples collected from on- and off-site monitoring wells. Equivalent source term concentrations were not calculated for TBA, since little information is available regarding the site-specific presence of TBA in gasoline released from the Terminal. Additionally, TBA is a possible degradation product of MTBE, which contributes to the uncertainty associated with assigning equivalent concentrations. Rather, the maximum concentration observed for each sampling event was used to represent the equivalent source term concentration. For a complete description of the transects, details regarding the data, methods used to estimate mass flux at the property boundary, and discussion of the results of the evaluation, refer to the Property Boundary Mass Flux Report (LFR 2004a).

The property boundary mass flux ranges and averages for each constituent for August 2001 through August 2003 were calculated as follows:

- MTBE: 231 to 1,289 g/day with an average of 937 g/day
- Benzene: 306 to 1,723 g/day with an average of 1,023 g/day
- TBA: 191 to 435 g/day with an average of 304 g/day.

These estimated mass flux values are within an order of magnitude of and slightly higher than the mass removal rates for the off-site groundwater extraction system, which were calculated as follows:

- MTBE: 93 to 876 g/day with an average of 375 g/day
- Benzene: 9 to 593 g/day with an average of 493 g/day
- TBA: 253 to 740 g/day with an average of 304 g/day

Several factors contribute to the differences between the property boundary mass flux estimates and the mass removal rates estimated for the off-site groundwater extraction system. These factors include uncertainties inherent in estimates of concentrations and groundwater flow terms used in both sets of calculations, natural attenuation mechanisms (most likely for benzene), influences by remedial efforts (LNAPL removal and soil-vapor extraction), and differences in the type of data used for each calculation (extraction system influent data versus monitoring well samples and Darcy flow).

The conclusions of the property boundary mass flux evaluation are summarized below:

- In general, the transect mass flux estimates and the extraction system mass removal rates are within an order of magnitude, and are likely more similar than as calculated due to conservative assumptions regarding LNAPL distribution, equivalent concentrations assigned, and natural attenuation and remediation efforts downgradient of the property boundary.

- The majority of the dissolved mass that the groundwater extraction system is removing is likely originating from source material located upgradient of the property boundary.

- Remedial actions that reduce or contain mass flux at the property boundary will likely be successful in decreasing downgradient concentrations in a relatively short time frame.

- The calculated transect mass fluxes should be used in remedial selection or feasibility evaluations and remedial design efforts.

3.0 NUMERICAL GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL

A three-dimensional numerical groundwater flow model, previously developed for the site by Camp Dresser & McKee (1999a), was expanded and recalibrated. The previous groundwater model was updated and refined to better represent site conditions and to improve confidence in its use as a predictive tool. Contaminant transport was simulated with a companion simulation code that can simulate three-dimensional contaminant migration for solutes subject to adsorption, dispersion, and first-order transformation. The flow and transport models were used to:

- estimate the dissolved mass flux of methyl tertiary-butyl ether (MTBE) at two transects, including a transect downgradient of recovery wells RW-3A through RW-7, and a transect south of recovery well RW-9
- simulate the effects of remedial extraction on the downgradient portion of the MTBE plume, in order to evaluate water quality impacts to a hypothetical future municipal supply well, and to estimate the time required to attain water-quality objectives in such a well

The estimates of flux and water quality impacts supplement the empirical mass flux evaluation summarized in the preceding section of this report. The numerical flow and transport model is documented in Appendix A.

By simulating historical MTBE releases to groundwater in the LNAPL area, a reasonable match to the current magnitude and extent of MTBE downgradient of the LNAPL source area was reproduced by the model. A depleting MTBE source was simulated in the off-site LNAPL source zone, and resulted in a simulated plume that is consistent with observed concentrations, likely plume arrival times, and empirically-estimated mass flux.

To calibrate the transport model to observed concentrations, likely plume arrival times, and empirically estimated mass flux, two degradation rates were specified. A satisfactory match between simulated and observed MTBE concentrations could not be achieved with a single transformation rate over the entire simulation period. The simulation was therefore divided into two periods: from 1991 to 2001, and from 2002 to 2010. Best match was achieved with an initial MTBE transformation constant of 0.0005 d^{-1} (corresponding to a half-life of 1,386 days), and an increased MTBE transformation rate of 0.009 d^{-1} (half-life of 70 days) effective from 2002 to 2010. Both of these values are in the range of reported literature values. The apparent transformation rate increase of over an order of magnitude since 2001 may be explained by one or both of the following hypotheses:

- Remedial pumping may have changed the flow field in the downgradient portions of the plume such that groundwater containing greater amounts of dissolved oxygen and other electron acceptors began to enter into the flanks of the plume, favorably affecting the plume biodegradation.

- There may be a long lag time for MTBE biodegradation processes to start, as microbes need time to adapt to an unfamiliar carbon source or to new geochemical conditions resulting from changes in remedial pumping rates and locations.

The empirical and numerical mass flux estimates are within the same order of magnitude. Both the empirical and the numerical mass flux values show an increase at the end of year 2000 for Transect 1 and in mid-year 2001 for Transect 2, followed by a steep decreasing trend with time. The rates of decrease in the empirical estimates are more rapid than predicted by the numerical model. This may be caused by a number of factors including aquifer heterogeneity, uncertainties in measurement and interpretation, and variable rates of natural attenuation in different portions of the plume.

Using the numerical transport model, these simulation results indicate that MTE mass flux across Transect 1 drops from 280 g/day in 2000 to 0.06 g/day in 2010. The transport model predicts that, in 2010, MTBE will remain in the lower permeability portions of the aquifer in concentrations of 10 to 42 µg/l.

A hypothetical supply well was placed in this future plume configuration in the location of well R-26, and pumped at 200 gpm. At this location, the alluvium is sufficiently thick to sustain 200 gpm of production. In addition, more than half of the aquifer thickness is above mean sea level, and the resulting regional drawdown is not likely to exceed 3 feet during average recharge conditions. The model predicts that maximum MTBE concentrations in such a well would be below 0.2 µg/l.

The simulations indicate that water quality objectives would be achieved in a hypothetical supply well downgradient of the remedial extraction wells should the well begin pumping in the year 2010. This prediction assumes that MTBE continues to attenuate, even at a relatively low rate.

4.0 PERFORMANCE EVALUATION OF REMEDIATION SYSTEMS

4.1 Soil-Vapor Extraction System

Extraction wells RW-1 through RW-7 are connected to an SVE system with a central extraction and treatment unit. The SVE system operated for nearly three years using a 250 cubic feet per minute (cfm) catalytic oxidizer-based vapor abatement system that was subsequently replaced with a 1,000 cfm catalytic oxidizer-based system, which started operation in August 2001.

The objective of the vapor extraction system is to remove volatile organic compounds (VOCs) from residual LNAPL in the vadose zone. Petroleum hydrocarbons are dissolved in groundwater, adsorbed to subsurface soil particles, and present as residual LNAPL. As the piezometric surface rises and falls, the LNAPL also rises and falls, resulting in a "smear zone." This smear zone is approximately as thick as the historical range of groundwater level variation. However, higher residual saturations of LNAPL may be contained within a much smaller interval due to the effects of hysteresis and relative permeability. The range of water level variation over the past 10 years is approximately 5 feet in the off-site residual LNAPL source area. The thickness of the smear zone adjacent to the groundwater extraction wells is likely greater due to the greater variation in water levels caused by pumping. This smear zone is a target of the off-site remedial efforts.

SVE effectively reduces hydrocarbon mass in two ways: vapor extraction removes soil vapor containing hydrocarbon constituents in the gas phase, and the extraction of soil vapor results in a corresponding introduction of fresh air to the subsurface soil. This introduced air generally has greater oxygen content than the removed soil vapor, which tends to create an aerobic environment and enhance biological activity. This aerobic environment may substantially increase the rate of in-situ biodegradation of hydrocarbon constituents.

4.1.1 SVE System Performance Evaluation and Phase I Expansion

A performance evaluation of the original SVE system (consisting of extraction wells RW-1 through RW-7) was completed to evaluate the system's area of effective influence. The Soil Vapor Extraction System Evaluation Report (LFR 2002c) was completed in partial fulfillment of Task C.3 of the TSO, and was submitted to the RWQCB on November 22, 2002. The specific objectives of the SVE system evaluation were to:

- correlate applied well-head vacuum (AWHV) to vapor-flow rates for off-site extraction wells
- determine an estimated zone of effective influence of the SVE system
- estimate operation parameters and the duration of remediation system operation for reduction and attenuation of VOC concentrations in soil

- determine optimal operation parameters for the SVE system based on the estimated area of effective influence in conjunction with additional site assessment and monitoring data

The estimated area of effective influence (or “zone of effective sweep” defined by a minimum critical pore-gas velocity within the unsaturated zone) was used to develop recommendations to augment and optimize operation of the existing SVE system.

Four SVE wells (RW-1, RW-3, RW-5, and RW-7) were used for the SVE field evaluation activities. Prior to testing, vapor monitoring probes were installed around each of the four aforementioned extraction wells at locations selected based on their respective historical operational vapor flow rates. Three groundwater/vadose zone observation wells and two vadose zone observation wells were installed parallel and perpendicular to the groundwater flow direction adjacent to extraction wells RW-1, RW-3, RW-5, and RW-7, for a total of 20 new monitoring locations. For a complete description of field activities, details regarding the data, methods used to estimate the zone of effective sweep, and discussions of the results of the evaluation, refer to the Soil Vapor Extraction System Evaluation Report (LFR 2002c).

The results of the SVE system evaluation indicated that the system could be improved with regard to vapor extraction efficiency (i.e., mass removed per volume of extracted soil gas) by making adjustments to the overall SVE system flow rate and by individual adjustments in flow rates at each of the existing SVE wells (i.e., RW-1 through RW-7). The estimate of required overall SVE flow rate was based on attaining a desired critical pore-gas velocity throughout the zone of interest. The required flow rate needed to establish this critical velocity varies according to the spacing of the SVE wells (i.e., closer well spacing allows lower required flows to establish the desired critical velocity). There is a lack of agreement in the available literature as to the total number of pore volume exchanges (PVE) required for SVE project completion. Some literature recommends as few as 200 to 400 PVE, while other literature recommends 2,000 to 5,000 PVE or higher. The wide variation in recommended PVE is likely due, at least in part, to the wide variation in subsurface characteristics from one site to another (i.e., fine-grained vs. coarse-grained soils or heterogeneous vs. homogenous soils). Important factors that will impact the total PVE requirement for the off-site source area at the Terminal are the amount of residual LNAPL mass, the discontinuous zones of fine-grained soils containing most of the LNAPL mass, and the ability of the SVE system to effectively influence zones containing that mass. The combination of having a relatively large total mass of residual LNAPL, and the fact that most of that mass appears to be contained in finer-grained zones, indicates that a higher number of PVEs will be required. Evaluation of SVE vapor concentrations over time combined with periodic monitoring of soil vapor probes that have been installed at strategic locations within the residual LNAPL source area will be used to monitor the performance of the SVE system.

The evaluation also indicated that the addition of an air-sparge process could potentially increase the efficiency of the off-site source area remediation via the SVE system with respect to attenuation of VOCs from residual LNAPL in the saturated zone, and adsorbed to soil in the capillary fringe.

Based on the recommendations presented in the Soil Vapor Extraction System Evaluation Report (LFR 2002c), several modifications to the existing SVE system were completed to optimize the remedial efforts at the site. These modifications included increasing the number of SVE wells based on the estimated average zone of effective sweep, and adding an air-sparge network to address the portion of the residual LNAPL smear zone located in the capillary fringe and saturated zones.

Initial system modifications were recommended for the vicinity of wells RW-3, RW-4, R-9, and R-12 (the "Phase I area"). Approximately 10 additional SVE wells were installed in the Phase I area with a well spacing of approximately 100 feet in order to evaluate the potential benefits of closer well spacing (e.g., lower required SVE flow rate and applied vacuum, and greater mass removal efficiency). Additionally, 24 air-sparge wells were installed in a grid area measuring approximately 60 feet by 80 feet for an initial performance evaluation to determine whether or not this technology should be expanded across the remaining off-site residual LNAPL area.

4.1.2 Phase I Expansion and Performance Evaluation

Additional performance evaluation activities were conducted to evaluate the Phase I expansion of the SVE system and the newly added air-sparge grid. The findings of this effort were reported in the Remediation System Technical Evaluation Report (LFR 2003c), which was completed in fulfillment of Task C.5 of the TSO and submitted to the RWQCB on July 8, 2003. The objective of the remediation system technical evaluation was to improve and enhance the remedial effectiveness of systems operating at the site.

The recommendations implemented from the Soil Vapor Extraction System Evaluation Report (LFR 2002c) included the installation and operation of:

- 11 new SVE wells (RW-10 through RW-20) and 1 targeted SVE well (RW-21) in the Phase I area
- an air-sparge system comprised of a total of 14 sparge wells in the Phase I area

For a complete description of field activities, details regarding the data, methods used to evaluate the system's performance, and discussions of the results of the evaluation, refer to the Remediation System Technical Evaluation Report (LFR 2003c).

SVE System Performance Evaluation

Performance evaluation results for SVE wells RW-18, RW-19, and RW-20 indicated an average radius of influence (ROI) at the respective applied wellhead vacuums (AWHV) and flow rates summarized below:

Well Name	ROI (ft.)	AWHV (in.-H_2O)	Flow Rate (scfm)
RW-18	50.8	77.5	7.77
RW-19	101.8	74.5	19.51
RW-20	61.2	74.0	20.63

The zone of effective sweep for SVE wells RW-18, RW-19, and RW-20 increased with an increase in applied vacuum and flow rate. A comparison of the radius of the zone of effective sweep vs. the applied flow rates indicated a generally linear relationship in the range tested. Linear interpolation to the most effective range indicated that the SVE wells should be maintained at a minimum flow rate in the range of 7 standard cubic feet per minute (scfm) to 17 scfm. Evaluation of AWHV vs. extraction flow rates at wells RW-18, RW-19, and RW-20 indicated that flow rates of approximately 5 to 15 scfm per well are achievable with a vacuum of approximately 20 to 50 inches water column. Laboratory and field data from vapor extraction tests at wells RW-19 and RW-20 indicated that effective mass removal rates are achievable using SVE, as a total estimated VOC mass of 21 pounds was removed in less than 12 hours of actual run time.

Based on the achievable SVE flow rates, radius of vacuum influence and effective sweep, and extracted VOC concentrations exceeding 2,700 milligrams per cubic meter (mg/m^3), the Phase I SVE evaluation supports the earlier conclusion that a well spacing of approximately 100 feet maximizes the extraction of high VOC vapor from the off-site source area and minimizes the extraction of vapor containing little to no VOCs.

Vapor extraction well RW-21 was installed with a 1-foot screen interval placed to discretely “target” a fine-grained layer of the smear zone. Testing of this well was conducted at both a low and high (relative to each other) AWHV to evaluate the relationship between vacuum ROI, AWHV, and flow rate for a well discretely screened in this fine-grained interval. A vacuum ROI of approximately 19.8 feet was observed at an AWHV of 81.6 inches of water column producing a flow rate of 6.93 scfm. A vacuum ROI of 23.4 feet was observed at an AWHV of 207.5 inches of water column producing a flow rate of approximately 15.37 scfm. The field data from this testing indicated that higher mass removal rates were achievable at the higher AWHV than those observed at the lower AWHV. The results also indicated that SVE wells discretely screened to target this fine-grained interval could be beneficial with respect to mass removal vs. time when compared to the more general SVE system (i.e., SVE wells with the longer 5-foot screened intervals). However, the area of effective influence is significantly limited due to the low permeability of this fine-grained layer. Even with this limitation, this type of “targeted” SVE may still have potential as an effective remedial alternative in isolated areas were the longer screened SVE wells by themselves are found to insufficiently attenuate the source area.

VOC concentrations exceeding 140,000 mg/m^3 were detected in vapors extracted from each of the new SVE wells (RW-10 through RW-20). Based on these results, regulating/isolation valves on wells RW-10 through RW-20 have been set to the fully open position to allow extraction of soil vapors at the maximum flow and mass removal rates. The flow rate, AWHV, and VOC concentration being extracted from each of these wells continue to be monitored on a regular basis to determine when individual wellhead adjustments are appropriate. VOC concentrations are expected to decrease over time as mass extraction rates become diffusion limited. Wells showing significant decreases in VOC concentrations will be regulated to lower flow rates in an effort to optimize the performance of the SVE system by focusing the available capacity of the system on the wells exhibiting higher mass extraction rates. When regulating individual wells in the future, flow rates and AWHVs will be adjusted such that the desired zone of effective sweep for each well is maintained.

The results of the SVE performance evaluation activities documented in the Remediation System Technical Evaluation Report (LFR 2003c), further support the prior conclusion that SVE wells screened in the vadose zone are an effective remedial technology for the removal of VOCs. Based on these results, the report recommended further expansion of the SVE system to address the remainder of the off-site residual LNAPL plume. SVE system operating parameters developed during evaluation of the Phase I expansion have been used as the design criteria for construction and operation of the expanded system. The report also recommended that vapor extraction from wells RW-1, RW-2, and RW-7 be terminated due to current and historically low VOC concentrations in the vapors extracted from these wells.

As of November 2003, 13 additional SVE wells (RW-22 through RW-34) have been installed in the off-site residual LNAPL source area. Construction of the additional SVE system infrastructure required for these wells to become operational was originally scheduled for the first quarter of 2004. However, conflicts between the planned construction activities and available access to the Qualcomm stadium parking lot have delayed the construction schedule, and these new wells are now expected to become operational during the second quarter of 2004.

Air-Sparge System Performance Evaluation

Performance evaluation results regarding the Phase I air-sparge grid indicated that air sparging could be an effective means of enhancing SVE effectiveness. VOC concentrations in the vadose zone were observed to increase by two to three orders of magnitude in the area influenced by air-sparge wells ASD-03 and AS-07, indicating that sparge-air has the ability to influence the targeted area and increase the mass extraction efficiency of the SVE operations. However, the area of sparge influence appeared more varied based on the results of pressure distribution testing, depending on the well used for injecting sparge-air into the subsurface.

A relatively long retention time was observed in the helium distribution testing, as illustrated by a significant lag time between injection of the helium into the formation via sparge wells and subsequent detection in the vadose zone monitoring points. These results may indicate that the sparge air was migrating up through the area of the smear zone targeted by the test, rather than migrating around it through a more permeable path.

Initial results of the dissolved oxygen (DO) testing appeared to indicate that air-sparging increased the DO content within the portion of the saturated zone targeted by the test, likely contributing to an improvement in biological degradation processes. Since helium was observed in all of the monitoring points during each of the helium distribution tests, the full extent of helium distribution (and sparge air) in the subsurface could not be determined. Although the performance evaluation results indicated at least partial capture of the injected sparge air, the results were inconclusive and indicated the need for additional testing for a longer duration of time.

The results from this additional testing were to be used in an effort to evaluate the maximum vertical flux of sparge air through the smear zone and determine injection flow rates that could effectively be controlled and captured by the SVE system (preventing the horizontal migration of fugitive vapors) and estimate what remedial benefit might be obtained by injecting sparge air at this rate.

The performance evaluation activities described above focused on the site-specific characteristics of the SVE and air sparge systems running independently of one another. Air sparging should only be expanded to enhance SVE in areas where it is both effective and necessary for achieving the remedial objectives. Therefore, additional testing was recommended to evaluate relevant parameters during concurrent operation of both the SVE and air-sparge systems to achieve the following objectives:

- determine the rate of capture of sparge air and the percentage of injected air that is recovered by the SVE system
- determine the most effective sparge rate
- estimate zone of effective sparge influence
- measure how the injection rate of sparge air affects the SVE zone of effective sweep
- estimate what the asymptotic soil gas and dissolved-phase concentrations of target chemicals of concern (COCs) would be with both the air-sparge and SVE systems operating concurrently
- estimate the time to reach asymptotic concentrations
- evaluate aerobic biodegradation rates both with and without air sparging

4.1.3 Continued Performance Evaluation

Performance evaluation activities related to the Phase I SVE expansion and air-sparge grid were continued, as recommended in the Remediation System Technical Evaluation Report (LFR 2003c), to observe relevant parameters during concurrent operation of both the SVE and air-sparge systems. Submittal of the Remediation System Continued Technical Evaluation Report (LFR 2004b) was not a requirement of the TSO but has been completed as a follow-up to the Remediation System Technical Evaluation Report, which was completed in partial fulfillment of Task C.5 of the TSO. The Remediation System Continued Technical Evaluation Report was submitted to the RWQCB on January 23, 2004.

The objective of the continued performance evaluation activities was to evaluate the concurrent operation of both the air-sparge and SVE systems and the effects of the air-sparge system on the efficiency of the SVE system to determine whether or not continued operation and/or additional expansion of the current air-sparge grid is warranted.

Estimated average vacuum ROIs and average radial distances to pore-gas velocities of 0.01 cm/s and 0.005 cm/s were evaluated for SVE wells RW-18, RW-19, and RW-20 under both non air-sparging and air-sparging operational conditions. The results of this evaluation are summarized below:

	RW-18		RW-19		RW-20	
	No Sparge-Air Injection	Sparge-Air Injection	No Sparge-Air Injection	Sparge-Air Injection	No Sparge-Air Injection	Sparge-Air Injection
Estimated Average Vacuum ROI	55.00	18.70	124.20	107.30	85.60	82.90
Ave. Radial Distance (ft.) to Pore-Gas Velocity of 0.01 cm/s	39.98	7.35	132.38	73.54	240.97	261.90
Ave. Radial Distance (ft.) to Pore-Gas Velocity of 0.005 cm/s	84.14	17.56	275.75	146.38	522.41	567.48

Results from RW-18 indicated that the relatively low extraction flow rate (22.1 scfm) was not sufficient to overcome the effects of injected sparge air. At this low extraction rate, monitoring points intercepted by the distributed sparge air were essentially choked off and thus the extraction well was no longer influencing these areas, which also resulted in pore-gas velocities of zero in these directions and ultimately a lower average pore-gas velocity relative to distance from the extraction point. Results from RW-19 and RW-20 indicated that the relatively high extraction flow rates (55.2 scfm and 72.9 scfm, respectively) were sufficient to overcome the effects of injected sparge air. Although the introduction of sparge air had an impact on the ROI and zone of affected sweep for wells RW-19 and RW-20, the ability of these two wells to maintain the ROI and zone of effective sweep for which they were designed was unaffected by the introduction of sparge air into the subsurface.

SVE wells spaced approximately 100 feet apart would still effectively capture soil vapor in the presence of air sparging; however, air sparge wells would need to be strategically placed such that the sparge wells and SVE wells do not create a short-circuiting effect in which sparge air flows directly from the sparge well to the SVE well. Air sparge wells operating at low injection flow rates (less than 5 scfm) would be required to be placed at distances of approximately 50 feet from the SVE wells, specifically in the nodes between the SVE wells. Additionally, results from helium capture testing indicated that SVE wells spaced approximately 100 feet apart are effective in capturing sparge air when air sparging is conducted at flow rates lower than 5 scfm.

Additional helium distribution testing results indicated that sparge air was fairly well distributed over the Phase I grid area even at injection flow rates ranging from 4.0 to 5.1 scfm. In each of the three tests, sparge air migrating vertically into the unsaturated zone from the saturated zone ranged from 20 to 47 percent of the total sparge air introduced into the subsurface. Sparge air reaching the unsaturated smear zone surrounding injection well AS-07 showed favorable results, as approximately 100 percent of the sparge air in this zone migrated vertically into the vadose zone surrounding AS-07. Injection wells AS-06 and ASD-03 showed less favorable results, with the percentage of the sparge air migrating vertically into the vadose zone being approximately 55 and 47 percent, respectively. The results of the additional helium testing have indicated that a preferential migration of sparge air exists in the horizontal direction when compared to the vertical direction. In each of the three tests, sparge air showed indications of being stratigraphically trapped either in the saturated zone and/or unsaturated-smear zone. Sparge air in both of these zones continued to preferentially migrate horizontally from the point of injection instead of percolating upward through the formation into the vadose zone, as desired.

Results for each of the three tests were somewhat favorable in that sparge air did appear to migrate from the point of injection up into the vadose zone. However, the test results also indicated that the rate at which sparge air migrates vertically versus its rate of horizontal migration makes the use of a low flow air-sparging system as an enhancement to the SVE system unfavorable.

Injecting sparge air at rates less than or equal to the maximum vertical flux of sparge air into the vadose zone would minimize the horizontal migration of the sparge air. However, these low injection rates are ineffective at increasing SVE vapor concentrations, making air-sparging an ineffective technology for enhancing the SVE operations. While increased air sparging flow rates (10.2 to 73.6 scfm) have been shown to be effective for increasing SVE vapor concentrations, the horizontal migration of the sparge air pose a risk for transient vapors to migrate beyond the zone where they would be effectively captured and removed by the SVE system. Increased air sparging flow rates (greater than 10.2 scfm) may be effective for targeting isolated areas where SVE capture can be improved through increased SVE well coverage.

Respirometry tests were conducted to measure the rate of biodegradation and ultimately the rate of contaminant mass removal within the Phase I sparge grid area. The initial respirometry test was conducted in a period when only soil vapor extraction was operating (i.e., no sparge air injection). The oxygen utilization rates observed during this initial test indicated that aerobic respiration is active in the Phase I area when SVE alone is operational. The second respirometry test was conducted to evaluate whether air sparging would enhance biodegradation rates. The test was initiated after the SVE and air-sparge systems were both operated continuously for approximately five weeks. The average oxygen utilization rates observed during this test were the same as those observed in the initial test. Operation of the SVE system has been shown to aerate the unsaturated-smear zone adequately for biodegradation. The SVE system is capable of pulling atmospheric oxygen into the subsurface to promote microbial respiration.

Operation of the air sparge system did not appear to enhance biodegradation of COCs in the unsaturated smear zone.

Low flow, continuous sparge testing was conducted to evaluate the effects of continuous, steady state air sparging on VOC concentrations in extracted soil vapor. Findings from the initial performance evaluation, reported in July 2003, indicated that air sparging had increased volatile fuel hydrocarbon concentrations in the vadose zone by two to three orders of magnitude. These findings were based on soil vapor probe samples taken before and after periodic air sparging tests conducted as part of the initial technical evaluation, and involved the operation of the air sparge system at much higher injection flow rates. Results from the low flow, continuous sparge test indicated that there is no added benefit to SVE mass extraction rates with the addition of air sparge operation. Operation at the decreased flow rate does not appear to result in an appreciable increase in soil gas VOC concentrations.

Groundwater samples from selected monitoring wells were analyzed prior to and during air-sparging activities to evaluate concentrations of inorganic constituents of groundwater as indicators of the existence and type of biological activity that may be occurring in the subsurface. The results of this analysis indicated that there is no discernable correlation between changes in nitrate or sulfate concentrations and active sparging. Dissolved oxygen (DO) concentrations ranged from 0.1 to 2.97 milligrams per liter (mg/l) and, as expected, increased during active sparging. Background DO concentrations observed at monitoring well R-19 were comparable and averaged about 2 mg/l over the last several quarters. Counter to the intuitive position that aerobic conditions should be stimulated by air sparging, the geochemical indicators point toward reducing, anaerobic (methanogenic) conditions before, during, and after active sparging. These conditions are similar to those that have generally been observed in this area of the site. This data appears to indicate that the sparging activities may not have been carried out long enough to stimulate strongly aerobic conditions in the formation.

Groundwater samples were also evaluated for concentrations of organic constituents to determine if dissolved phase concentrations of COCs decreased when sparge air was introduced to the subsurface. No discernable correlation was observed between the introduction of sparge air into the subsurface and changes in dissolved-phase concentrations of COCs. Concentrations of COCs increased in some of the wells monitored while decreasing in others during this period. It is inconclusive as to whether or not COCs decreased due to air stripping induced by air sparging or because of increased biological activity due to increased oxygen concentrations from the injected sparge air. It does, however, appear that air sparging did not significantly decrease dissolved phase COCs in the saturated zone.

Overall, the results of the continued performance evaluation activities indicated that air sparging is ineffective as an SVE enhancement at injection flow rates ranging from 4.0 to 5.1 scfm. Even at these low air injection flow rates, preferential migration of sparge air in the horizontal direction when compared to the vertical direction indicates that the injected air was stratigraphically trapped beneath tighter, less-permeable soils. Sparge air continued to preferentially migrate horizontally from the point of injection as opposed to percolating upward through the formation into the vadose zone where it could be captured by SVE. Additionally, at these lower flow rates the air sparging was not effective as an SVE enhancement in that it did not appear to: 1) increase SVE mass extraction rates, 2) increase biodegradation of COCs, 3) stimulate an aerobic environment, or 4) decrease dissolved phase COCs in the saturated zone.

Injection flow rates less than or equal to the apparent maximum vertical flux of sparge air into the vadose zone (less than 4.0 scfm) appeared to minimize the horizontal migration of sparge air, which increases the confidence that the sparge air will be captured by the SVE system and not become fugitive. However, it is also reasonable to assume that air sparging at the reduced injection flow rates would be even less effective as an SVE enhancement than it appeared to be with injection flow rates greater than 4.0 scfm.

Results from the initial air sparge tests reported in the Remediation System Technical Evaluation Report (LFR 2003c) indicated that air sparging with injection flow rates of 10.2 to 73.6 scfm was effective in increasing VOC concentrations in extracted vapors, indicating that air sparging could be an effective enhancement to SVE. Based on the subsequent performance testing, however, these higher injection flow rates now appear to be greater than what the formation is able to accept and created air pockets around the injection wells. The resulting subsurface pressures likely forced the sparge air to penetrate the less-permeable soils and produced the appearance that air sparging was effective in increasing the SVE mass extraction rates. However, operation of the air-sparging system at these higher injection flow rates now does not appear to be feasible due to the associated risk of producing fugitive vapors that could migrate horizontally beyond the control of the SVE system.

Monitoring of aerobic biodegradation respiration rates, dissolved-phase concentrations of COCs and natural attenuation monitoring indicators both with and without air sparge did not indicate that the introduction of sparge air into the subsurface was effective in reaching objectives of air sparging as an SVE enhancement. Increases in biodegradation of COCs, the stimulation of an aerobic environment, and the decreasing of dissolved phase COCs in the saturated zone did not appear to result from injecting sparge air into the subsurface for a period of four weeks. Air sparging may prove to be beneficial in enhancing SVE should the air sparge system be operated for longer periods; however, because of the preferential migration of sparge air in the horizontal direction, a risk for transient vapors to migrate beyond the zone where they could be effectively captured and removed by the SVE system would still exist.

4.1.4 Recommendations for Additional Optimization of Soil-Vapor Extraction System

LFR recommends continuing with soil vapor extraction activities at the site in the absence of sparge air. LFR recommends continuing with the more aggressive remedial optimization activities which include monitoring and making adjustments to the overall SVE flow rate and at individual SVE wells to optimize vapor extraction efficiency (i.e., pounds of mass removed/cubic foot of vapor extracted). Flow rates, vacuums, and VOC concentrations will continue to be monitored monthly to biweekly at all SVE wells to evaluate changes in extraction effectiveness and to evaluate the time necessary for extracted soil vapors to reach asymptotic levels. To improve vapor extraction effectiveness for the overall SVE system, each individual well will continue to be evaluated and adjusted accordingly, utilizing their respective regulating/isolation valves. Those wells showing low VOC concentrations will be isolated from the SVE system and rebound of VOCs concentrations will be monitored monthly to biweekly. Wells isolated from the system will be placed back on-line as warranted by rebound concentrations.

4.1.5 Recommendations for Air Sparge System

LFR is not recommending any expansion or further use of the air sparge system as an enhancement to SVE activities.

4.2 Groundwater Extraction System

4.2.1 Groundwater Extraction Evaluation of Existing Recovery System

A performance evaluation of the original groundwater extraction system (consisting of extraction wells RW-3 through RW-7) was completed to evaluate the system's area of effective influence. The Groundwater Extraction Evaluation of Existing Recovery System Report (LFR 2002b) was completed in partial fulfillment of Task C.3 of the TSO, and was submitted to the RWQCB on November 21, 2002.

The specific objective of the groundwater extraction system evaluation was to evaluate the efficiency and effectiveness of the existing groundwater extraction system so that future system expansion and optimization could be determined to address dissolved-phase MTBE impacts downgradient of the existing system. The scope of work completed to achieve this objective included:

- evaluation of hydraulic gradients within the capture zone
- evaluation of groundwater quality temporal trends
- evaluation of the hydraulic characteristics of the alluvium to determine well efficiency and refine the area of effective influence of the existing groundwater extraction system relative to the areas of impact

The estimated area of effective influence of the existing system was subsequently used in conjunction with other site data to optimize pumping operation and determine future extraction well placement. The following tasks were completed in evaluating the efficiency and effectiveness of the groundwater extraction system:

- review of lithology and well installation logs
- containment performance monitoring
- aquifer testing

For a complete description of the scope of work, details regarding the data, methods used to evaluate the hydraulic characteristics of the alluvial aquifer, and discussion of the results of the evaluation, refer to the Groundwater Extraction Evaluation of Existing Recovery System Report (LFR 2002b).

The maximum flow rates that could be obtained from the existing extraction wells appeared to vary considerably, from as low as less than 3 gpm from well RW-3 up to approximately 94 gpm from well RW-7. LFR reviewed the extraction well installation logs and lithologic cross sections from previous investigations at the site, as well as lithologic information obtained from additional observation and groundwater monitoring wells installed in the immediate vicinity of the recovery wells. Based on these data and a review of the original well installation report, LFR made preliminary determinations as to whether the wide variation in groundwater extraction rates was due to variations in the lithology surrounding each well, damage to the borehole caused during well drilling and completion, or well construction.

Well RW-3 is the westernmost extraction well and its lithologic log indicates a markedly different lithology, with most of the alluvium below the water table classified as either sandy clay or interbedded sandy clay and silty sand. Well RW-3 is also the extraction well located closest to the northern edge of Mission Valley, and may potentially be installed in non-fluvial sediments originating from the surrounding mesas.

Six dual-zone monitoring well clusters (R-32AS/AD, R-33AS/AD, R-34AS/AD, R-35AS/AD, R-36AS/AD, and R-37AS/AD) were installed downgradient of the existing extraction wells within the estimated area of effective influence. Five additional monitoring well clusters (R-38AS/AM/AD through R-42AS/AM/AD) were installed downgradient of the estimated area of effective influence. These wells were installed to monitor groundwater quality and hydraulic gradients to determine whether temporal and spatial variations in contaminant distribution and groundwater flow directions are consistent with hydraulic containment.

The extent of hydraulic capture of the existing groundwater extraction system was evaluated from groundwater level measurements, interpreted groundwater flow patterns, and temporal and spatial variations in groundwater quality data. If containment is complete, all groundwater flow from the source area (i.e., the region containing residual LNAPL) should follow flow pathlines that terminate at the groundwater extraction wells. In general, performance monitoring involved: 1) measuring and interpreting groundwater levels (hydraulic heads), and 2) groundwater quality monitoring.

Groundwater levels were measured to evaluate hydraulic gradients and groundwater flow paths in the area of residual LNAPL and extraction wells RW-3 through RW-7. This data indicated that groundwater flow in the shallow alluvium from the source area follows pathlines that terminate at the groundwater extraction wells. Additionally, upward hydraulic gradients from the deeper alluvium to the shallow alluvium were observed in all six dual-zone well pairs (R-32 through R-37) located immediately downgradient of the extraction wells.

Groundwater quality data from the downgradient monitoring well network was inconclusive regarding the current extent of hydraulic capture as of the date of the submittal of the extraction system evaluation report (LFR 2002b), because monitoring wells R-38 and R-40 through R-42 had not been in place for a sufficient amount of time to evaluate concentration trends over time. However, groundwater quality data have continued to be collected and analyzed as part of the ongoing quarterly monitoring activities, and the concentration trends that have been observed in this data are consistent with hydraulic containment of the residual LNAPL source area. Containment performance monitoring of the groundwater extraction system continues to be conducted as part of the ongoing quarterly monitoring activities.

Pumping tests were performed on recovery wells RW-3, RW-5, and RW-7. Prior to beginning the pumping tests, transducers were placed in two monitoring wells associated with RW-7 (R-34AD and RW-7-P3DS). The groundwater extraction system was then shut down and groundwater levels in the aquifer were allowed to recover to near steady-state levels. A minimum of 24 hours of monitoring groundwater levels was performed prior to initiating the first of the three pumping tests to monitor background trends and barometric influences. Additionally, water levels were measured in well R-16 one day prior to and throughout the duration of all three pumping tests to evaluate background changes that may influence water levels in the observation wells. Well R-16 was selected for monitoring background water level changes since it is located outside of the influence of any of the three pumping tests.

Prior to each full pumping test, a step-rate drawdown test was conducted to get an estimate of the maximum practical pumping rate before the constant-rate aquifer test began. Following the step drawdown tests, constant-rate pumping tests were performed. Each constant-rate pumping test was conducted for 48 hours. At the end of the 48-hour pumping period, the pump was turned off and recovery data were recorded until the groundwater level had recovered to approximately 95 percent of its pre-pumping steady-state level.

Drawdown data from each observation well monitored during each test were plotted and interpreted manually to validate the data and to evaluate evidence of boundary conditions and other aquifer responses. Then, storativity and transmissivity were calculated using AQTESOLV® v2.13, an aquifer test analysis program written by HydroSOLVE, Inc.

The drawdown and recovery data were plotted and analyzed using analytical solutions that were consistent with the conceptual model of the subsurface flow system and with the character of the data obtained. Analytical methods used include those developed by Theis, Cooper-Jacob, and Hantush-Jacob. Well bore storage effects were observed at the beginning of the pumping tests. For this reason, the analytical solutions were fitted to the latter portions of each drawdown curve, which represents the later time data when well bore storage effects have diminished. The later time data were also used for fitting type curves to the recovery data. Other analytical methods that relax one or more of the listed assumptions were considered, depending on the observed responses.

Constant rate pumping tests were conducted on extraction wells RW-3, RW-5, and RW-7 with pumping rates of approximately 1.5 gpm, 61 gpm, and 58 gpm, respectively, maintained throughout the tests. Significant drawdown was observed in observation wells during the RW-5 and RW-7 pumping tests. No significant drawdown was observed in any of the observation wells during the RW-3 test, even though there was approximately 9 feet of drawdown in that pumping well. This indicated that there is either poor communication between the well and the aquifer or the aquifer material does not produce water at any significant rate, and is likely a combination of these two factors.

Overall, the Hantush-Jacob method of analysis provided the best (i.e., most unique and unambiguous) curve fits. Alluvial sediments such as those in Mission Valley often respond as a semi-confined, slightly leaky aquifer, which is consistent with the use of the Hantush-Jacob method. Therefore, the results from this method were considered the most reliable and are summarized below.

In general, the range of transmissivity and hydraulic conductivity results were similar for the RW-5 and RW-7 tests. Using the preferred method of analysis (Hantush-Jacob), the transmissivity values ranged from 4,200 to 13,000 square feet per day (ft^2/day) with an average of 8,000 ft^2/day for the RW-5 test, and from 2,500 to 8,300 ft^2/day with an average of 5,100 ft^2/day for the RW-7 test. In general, the deeper observation wells had faster response times, lower apparent storativity, and higher apparent transmissivity. These trends were more apparent in the RW-5 test than in the RW-7 test, and are consistent with the observed presence of coarser-grained materials near the base of the alluvial aquifer overlying the Friars Formation.

Leakage coefficients ranged from 0.023 to 0.087 for the RW-5 test, with an average of 0.056. For the RW-7 test, leakage coefficients ranged from 0.012 to 0.41, with an average of 0.12. The higher apparent leakage in the RW-7 test could be due to increased leakage between water-bearing zones, or to other sources of water, such as recharge from surface water bodies (i.e., Murphy Canyon Creek).

Hydraulic conductivity values were calculated by dividing the transmissivity values by the thickness of the aquifer. The aquifer was estimated to be 38.7 feet thick for the RW-3 test, 45.2 feet thick for the RW-5 test, and 38 feet thick for the RW-7 test.

The method that produced the best curve fits in the RW-5 test was the Hantush-Jacob method, with an average hydraulic conductivity value of 180 ft/day. The curve fits were not as consistent in the RW-7 test, but the average K values for the Hantush-Jacob method and the Theis recovery method were 140 ft/day and 110 ft/day, respectively. These values were subsequently used for the groundwater velocity and stagnation point calculations.

Data from observation well RW-6 consistently show high K values from both the RW-5 and RW-7 pumping tests. Values range from 200 ft/day for the RW-5 test to 220 ft/day for the RW-7 test using the Hantush-Jacob method. The hydraulic conductivity results from R-36AD and R-35AD were also relatively high, with 180 ft/day and

290 ft/day, respectively. Both of these wells are screened near the bottom of the alluvium.

Hydraulic data from the RW-3 test do not appear to be representative of the larger aquifer system at the site.

Well efficiencies and radius of effect were also evaluated for wells RW-5 and RW-7. Well RW-5 was determined to have a well efficiency of 21 percent and radius of effect of approximately 650 feet. Well RW-7 was also determined to have a well efficiency of 21 percent with a radius of effect of approximately 500 feet.

Groundwater velocity was calculated at an average of 3.6 ft/day in the wells around RW-5 and 2.2 ft/day in the wells around RW-7. The downgradient extent of capture (stagnation points; the distance beyond the pumping well where groundwater flow is not affected) averaged approximately 47 feet at RW-5 and 87 feet at RW-7. RW-3 was not evaluated, since it had a very low transmissivity. The expected stagnation point at this well was expected to be less than a few tens of feet.

Using the formula of $2\pi r$ (r = stagnation point), the cross-gradient capture width was calculated. The capture width for RW-5 was estimated to be 290 feet, and the capture width for RW-7 was estimated to be 550 feet. Because the drawdown created by each pumping well tends to overlap with adjacent pumping wells, the extent of capture during full system operation is expected to vary significantly from these predictions and be greater than the individual capture widths.

Based on the results of this evaluation, LFR concluded that the existing groundwater extraction well network appeared to contain dissolved-phase hydrocarbons migrating in the shallow alluvium from the residual LNAPL source area, with the potential exception of the area west of extraction well RW-3, where the data were not conclusive. Given the historically poor performance of RW-3 as a groundwater extraction well, LFR recommended that this well be abandoned and replaced with a new extraction well. Based on lithologies observed during the installation of the observation wells around RW-3, a replacement well (RW-3A) was installed approximately 20 feet to the northeast of RW-3, as this was determined to be a suitable location that could provide more effective containment in this area.

Additionally, LFR recommended the installation of groundwater extraction wells RW-8 and RW-9 to expand the extent of dissolved-phase hydrocarbon capture downgradient of the existing system, and to reduce uncertainties regarding the extent of hydraulic capture in the deeper alluvium. Both of these two new extraction wells, as well as RW-3A, were constructed as fully penetrating wells with screened intervals extending from the water table down to the top of the Friars Formation to target capture from the full vertical extent of the saturated alluvium.

Additional groundwater monitoring wells associated with new extraction wells RW-8 and RW-9 were also installed in order to further evaluate the effectiveness of the groundwater extraction system.

Based on the recommendations of this evaluation, the monitoring of hydraulic heads and contaminant concentration trends in the area of the groundwater extraction system, along with monitoring of mass removal rates at each individual extraction well, have continued as part of the ongoing quarterly monitoring activities. This data continues to be used to adjust the system operation to optimize its performance and efficiency while maintaining adequate hydraulic containment.

4.2.2 Performance Evaluation of Modified Groundwater Extraction System

Additional performance evaluation activities were conducted to evaluate the modifications to the groundwater extraction system. The findings of this effort were reported in the Remediation System Technical Evaluation Report (LFR 2003c), which was completed in fulfillment of Task C.5 of the TSO and submitted to the RWQCB on July 8, 2003. The objective of the remediation system technical evaluation was to improve and enhance the remedial effectiveness of systems operating at the site.

The recommendations implemented from the Groundwater Extraction Evaluation of Existing Recovery System Report (LFR 2002b) included the installation and operation of:

- groundwater extraction well RW-3A to replace the historically poor performing extraction well RW-3
- groundwater extraction wells RW-8 and RW-9

For a complete description of the scope of work, details regarding the data and methods used to evaluate the performance of the groundwater extraction system, and discussion of the results of the evaluation, refer to the Remediation System Technical Evaluation Report (LFR 2003c).

As with the performance evaluation of the previously existing groundwater extraction system, the extent of hydraulic capture of the modified extraction system was evaluated from groundwater level measurements, interpreted groundwater flow patterns, and temporal and spatial variations in groundwater quality data. If containment is complete, all groundwater flow from the source area (i.e., the region containing residual LNAPL) should follow flow pathlines that terminate at the groundwater extraction wells. Additionally, groundwater flow from the higher concentration central core of the dissolved-phase MTBE plume should follow flow pathlines that terminate at extraction wells RW-8 and RW-9. In general, performance monitoring involved: 1) measuring and interpreting groundwater levels (hydraulic heads), and 2) groundwater quality monitoring.

The data evaluated for this effort indicated that the expanded groundwater extraction system has a capture zone that is wider in the cross-gradient direction than is necessary for hydraulic containment of the residual LNAPL area and the dissolved-phase MTBE plume. Mesa-front recharge from the northwest and recharge from Murphy Creek to the east appear to be contributing to hydraulic control in the off-site residual LNAPL area. Between November 2002 and February 2003, the total mass of MTBE in the off-site plume decreased by approximately 50 percent, while the total volume of affected groundwater in the off-site area containing an MTBE concentration greater than 1 µg/l decreased by approximately 25 percent. In general, the differences in the volume of affected groundwater and total MTBE mass are likely caused by changes in source strength, mass removal and containment of the plume by the groundwater extraction system, and attenuation of the plume downgradient of the source (LFR 2003a).

Additional recommendations for operation of the groundwater extraction system presented in the technical evaluation report included the following:

- Reduce the pumping rate at RW-3A to ~15 gpm from ~20 gpm, which is similar to the pumping rate at neighboring extraction wells and should not compromise hydraulic containment. Continue evaluating the effectiveness of hydraulic containment through analysis of future quarterly groundwater gauging and quality data.

- Reduce the pumping rate at RW-5 to ~15 gpm from ~40 gpm, which is similar to the pumping rate at neighboring extraction wells and should not compromise hydraulic containment. Continue evaluating the effectiveness of hydraulic containment through analysis of future quarterly groundwater gauging and quality data.

- Continue monitoring groundwater quality data in the area west of the stadium to evaluate the effectiveness of hydraulic control and the potential for reducing the pumping rates at RW-8 and RW-9. Specifically, decreasing MTBE concentration trends should be observed for several quarters in monitoring well R-17 and monitoring well clusters R-42 and R-47 before considering reducing the pumping rates at extraction wells RW-8 and RW-9.

4.2.3 Recommendations for Additional Optimization of Groundwater Extraction System

The groundwater extraction system is frequently monitored in an effort to continually optimize extraction goals. The existing groundwater extraction system serves two primary purposes. First, wells RW-3A through RW-7 provide containment of the residual LNAPL source area, preventing further downgradient migration of dissolved-phase contaminants. Second, extraction wells RW-8 and RW-9 provide capture of the higher concentration central core of the dissolved-phase plume located downgradient of the residual LNAPL source area.

Recommendations for on-going optimization of the groundwater extraction system include the following:

- Continue monitoring individual extraction well flow rates and mass removal characteristics via monthly wellhead sampling.

- Continue monitoring and evaluating hydraulic heads and temporal groundwater quality data trends via the quarterly monitoring program to ensure continued hydraulic containment of the source area and capture of the dissolved-phase contaminant plume.

- Optimize individual wellhead flow rates in an effort to minimize extraction rates while maintaining adequate hydraulic containment and capture of the dissolved-phase contaminant plume.

5.0 HEALTH RISK ASSESSMENT

A health risk assessment was completed for the off-site areas downgradient of the Terminal and a separate health risk assessment for the on-site area is currently in progress. The off-site risk assessment, submitted in fulfillment of Task A.4 of the TSO, included a receptor pathway assessment task (Task A.3 of the TSO). The on-site risk assessment is not required in the TSO, but is being performed in support of on-site containment and remediation strategies, and to provide completeness in the evaluation of risk due to site contamination. The following sections summarize the Receptor Pathway Assessment (LFR 2002a), the Health Risk Assessment, Off-Site Areas Report (ENVIRON and LFR 2003), the Supplemental Health Risk Assessment, Off-Site Areas Report (ENVIRON and LFR 2004), and the On-Site Health Risk Assessment (to be submitted in early to mid 2004).

5.1 Off-Site Health Risk Assessment

The Receptor Pathway Assessment identified existing and potential future receptors and exposure pathways through the development of a conceptual off-site exposure model. The constituents of concern included MTBE, TBA, and benzene, toluene, ethylbenzene, and total xylenes (BTEX) in accordance with the State approved Risk Assessment Work Plan. The selection of the potentially complete current and future pathways was determined by evaluating the conceptual exposure model in relation to current and expected land use and parcel zoning, current and expected groundwater use, and beneficial uses of groundwater and the San Diego River. Quantitative analyses (e.g., calculations and/or direct measurements) were recommended for identified current potentially complete exposure scenarios:

- inhalation of MTBE and BTEX and odor perception of MTBE in ambient and indoor air by Stadium workers and visitors as a result of volatilization from groundwater and affected soils
- dermal absorption, inhalation, and incidental ingestion of BTEX and MTBE, and odor perception of MTBE by recreational users of the San Diego River
- dermal absorption and ingestion exposures to sensitive ecological receptors by affected San Diego River water

Quantitative analysis was also recommended for identified potential future scenarios:

- ingestion and dermal absorption of potentially affected groundwater by residents
- inhalation of MTBE and BTEX and odor perception of MTBE by construction workers
- dermal absorption of MTBE and BTEX by construction workers

The objective of the risk assessment was to characterize any potential human health or ecological risks due to the above exposures. Cancer risks and noncancer hazard indices (HIs) were estimated based on guidance provided by the U.S. Environmental Protection Agency, and the basis for acceptable risk levels is in The National Contingency Plan (NCP) (40 Code of Federal Regulations 300). The estimated cancer risks, which included all chemicals and complete exposure pathways evaluated, were well below the NCP target risk range of 10^{-4} to 10^{-6}. The estimated noncancer HIs for the receptor populations evaluated were all well below the target of one for all of the receptors evaluated.

Risk-based target concentrations (RBTCs) for soil gas were developed for the most exposed populations in ambient and indoor air environments – the parking lot attendant in ambient air and the future ground-level Stadium worker in indoor air. Measured soil-gas levels were all significantly below soil gas RBTCs. Using the maximum measured concentration in groundwater, indoor and ambient air concentrations were calculated for Stadium workers (indoor), Stadium visitors (outdoor), parking attendant (outdoor), and construction workers (outdoor). A comparison of the estimated indoor and outdoor air concentrations with air odor thresholds shows that the estimated values are well below levels of concern for odor issues.

Impacts to potential potable groundwater uses were evaluated by comparing current groundwater concentrations to applicable water quality objectives. Within the area of residual LNAPL, groundwater concentrations of MTBE, BTEX, and TBA exceeded applicable water quality objectives. Outside the area of the residual LNAPL, water quality objectives were exceeded only for MTBE, benzene, and TBA.

For the evaluation of surface water in the San Diego River, “grab” samples were collected in 1999 and 2002. MTBE was the only constituent detected in the samples. The concentrations of MTBE detected in the samples were indicative of possible non-point sources. These results, coupled with the depth of the plume near the river, suggested that current or future impacts to beneficial uses of the San Diego River are unlikely. In addition, the detected MTBE concentrations in the San Diego River are well below odor thresholds for water and water quality goals for aquatic life protection.

A conceptual risk management plan (“management plan”) was presented to effectively and efficiently contain source areas and remediate the hydrocarbon plume emanating from the Terminal. The management plan identified how proposed remedial activities will contain the plume. The three main elements to the management plan were residual LNAPL containment, dissolved hydrocarbon plume remediation, and LNAPL remediation. In addition to reduction in the chemicals of potential concern and LNAPL mass reduction, and in the case that LNAPL is technically infeasible or cost prohibitive to remediate, pathway elimination was identified as a consideration. Pathway elimination is commonly addressed through the use of institutional and engineering controls.

5.2 On-Site Health Risk Assessment

An on-site risk assessment is currently being conducted to characterize reasonably potential human health risks due to exposure to chemicals at the Terminal property. Potentially exposed populations include current and future Terminal workers and subcontractors and potential future groundwater users. Potentially complete exposure pathways being evaluated include inhalation of indoor and outdoor air, exposure to vapors during potential future trenching activities, incidental ingestion of soils by current subcontractors in the manifold area, and ingestion or inhalation of and dermal contact with groundwater. Inhalation pathways are being evaluated with the screening-level model described by Johnson and Ettinger (1991). A California EPA box-mixing model is being used to evaluate outdoor air exposure pathways (CalEPA 1994). Groundwater exposures are evaluated by comparison to water quality objectives for the Mission San Diego Groundwater Basin (CRWQCBSDR 1994).

Preliminary results of the forward risk calculations and evaluations of risk-based concentrations for future scenarios indicate additional data collection activities may be required to more accurately assess potential exposures to indoor air. Additional data collection needs may include sub-slab soil gas sampling and indoor air sampling. The on-site risk assessment report is scheduled for completion in early to mid 2004.

6.0 PROPOSED MILESTONES

The remedial goals, strategy, implementation plan, and milestone dates to accomplish those remedial goals in the off-site area are shown in Table 1. The following sections also provide discussion of proposed milestones in accordance with the TSO requirements.

The proposed milestones, and associated milestone cleanup dates for the off-site area have been derived based on operation of the proposed remedial system to achieve the following remedial goals stated in the TSO:

- "Restore water quality in the portion of the Mission San Diego hydrologic sub area proposed for development by the City of San Diego for municipal use."
- "Clean up all off-site pollution."

An interim remedial objective for the off-site area is to enable beneficial use of groundwater within portions of the Mission San Diego Hydrologic Sub Area proposed for development by the City of San Diego for municipal use while off-site remedial activities continue. This objective is accomplished by achieving a COC mass flux directly upgradient of the area of proposed groundwater use (i.e., downgradient of Transect 2

[Figure 3]; LFR 2003b and 2003d) that is less than the proposed mass flux targets protective of drinking water supply. An additional interim remedial objective for the off-site area is to reduce the COC mass flux from of the off-site residual LNAPL area to levels below the mass flux targets after active off-site remedial activities have ceased.

The remedial strategy to achieve the above-mentioned goals and interim remedial objectives includes the following:

- Reduce the dissolved-phase mass flux of COCs from the off-site source area to the Mission San Diego Hydrologic Sub Area proposed for development for municipal use to below the mass flux targets. Reduction of COC mass flux from this area will protect potential receptors and restore the aquifer for beneficial use within a reasonable time frame. Continued operation of a containment remedy downgradient of the off-site source area is intended to reduce or eliminate the mass flux from this area and protect beneficial uses of groundwater downgradient of that barrier.

- Reduce COC mass flux from the Terminal property to the off-site area. It is not currently certain what portion of the COC mass recovered by the downgradient source containment barrier (wells RW-3A through RW-7) originates from on-site vs. off-site residual LNAPL areas. However, property boundary mass flux estimates (LFR 2004a) indicate that reduction/elimination of COC mass flux from the Terminal property would be likely to substantially reduce the groundwater COC mass flux downgradient of the off-site source area in a relatively short time frame.

- Reduce measurable thicknesses of LNAPL in the off-site area to less than 0.01 foot.

- Reduce COC concentrations within the off-site source area to levels that enable the mass flux of COCs in groundwater from this area to be less than the mass flux targets with no further containment of this area.

Proposed remedial measures necessary to implement the off-site area remedial strategy consist of the following:

- Expand the SVE system to more effectively treat the entire off-site residual LNAPL source area for COC mass reduction.

- Install a containment barrier at the southern property boundary of the Terminal to intercept dissolved-phase COCs from migrating off-site.

- Continue operation of the existing containment barrier at the downgradient edge of the off-site residual LNAPL area.

This overall remedial strategy represents a proactive and logical approach toward accomplishing the remedial objectives and TSO goals. Reduction/elimination of the COC mass flux from the Terminal property, combined with SVE in the off-site source area and additional containment downgradient of the off-site source area, should be successful in meeting the interim remedial objectives for the off-site area. If natural attenuation is demonstrated to be sustainable and effective within an acceptable timeframe, it may be relied upon to reduce the remaining COC concentrations in off-site groundwater to Basin Plan water quality objectives, after the interim remedial objectives have been achieved.

Complete removal of all residual LNAPL from the off-site area is not an objective of the proposed remedial measures, nor is it necessary to accomplish the remedial goals. Active remedial measures in the off-site area may be terminated once the interim remedial objectives have been achieved and beneficial use of the Mission San Diego Hydrologic Sub Area proposed for development has been restored (SWRCB Resolution 92-49). It is expected that any residual LNAPL remaining in the off-site area, after active remedial measures are terminated, will naturally attenuate over time.

This overall strategy is designed to expediently progress toward accomplishing the remedial objectives for the off-site area. Further monitoring and evaluation of the subsurface conditions along with continued evaluation of treatment system operation and performance will result in a more thorough understanding of where to focus any warranted future remedial enhancements.

The following discussion divides the proposed project milestones into three categories. The first category is entitled “implementation milestones”; these milestones are related to remedy implementations. The second category is entitled “clean-up milestones,” which are related to remedial performance goals. And the third category is entitled “clean-up goals,” which addresses applicable Water Quality Objectives from the Basin Plan, both numerical and narrative (CRWQCBSDR 1994). These milestones and cleanup goals are further summarized in Table 1.

6.1 Implementation Milestones

Proposed milestones for implementation of the off-site area remedial strategy are listed below:

- Operation of the source containment barrier downgradient of the off-site residual LNAPL area.

  This barrier is currently operational and is successfully intercepting COC mass flux at the downgradient edge of the off-site residual LNAPL area.

- Expansion of SVE system to provide adequate coverage over the remainder of the off-site residual LNAPL area.

  SVE system expansion to address the entire off-site residual LNAPL area is underway at the time of this report. The implementation milestone to complete installation and begin operation of the expanded system is August 1, 2004.

- Installation of a containment barrier at the southern boundary of the Terminal property.

  The appropriate barrier technology will be selected based on completion of a site-specific feasibility evaluation that is currently underway. Current plans include selection of a barrier technology prior to the end of 2004, with the barrier to be installed and operational on or before December 31, 2005. Although selection of the most appropriate technology remains to be finalized, preliminary indication of the feasibility evaluation is that a hydraulic barrier is the most likely technology to be implemented. A hydraulic barrier located at the southern property boundary would be considered a reliable and cost-effective method for cutting off mass flux currently migrating offsite from the site property boundary. A hydraulic barrier would also be reliable in regard to the capture of any potentially remaining pockets of mobile LNAPL that might be conveyed to the property boundary from upgradient locations.

  The strategic placement of additional groundwater extraction wells for the hydraulic barrier would provide the additional benefit of serving as an enhancement to the expanded SVE system in the off-site residual LNAPL zone. This enhancement would be accomplished by eliminating/reducing additional hydrocarbon mass flux from Murphy Canyon into the off-site source area, and by further lowering the groundwater table in the off-site area. Additional lowering of the groundwater table in the off-site source area would further expose the LNAPL smear zone to SVE influence, which would enhance the overall remedial system in a few basic ways:

  - Exposing a greater amount (perhaps all) of the off-site residual LNAPL to SVE influence and the related mass removal would result in more effective overall mass reduction of COCs in the off-site source area, potentially accelerating attainment of groundwater and soil vapor COC target concentrations.

  - The portion of the residual LNAPL smear zone presently located below the groundwater table is strongly anaerobic. Exposing a greater portion of this area to SVE influence should increase the rate of oxygen replenishment to this zone and enhance the biodegradation component of the overall remedial strategy. Results of the Continued Performance Evaluation have indicated that aerobic activity was present in zones that were exposed to SVE (i.e., vadose zone areas), while saturated zone areas remained basically anaerobic.

  - Additional lowering of the groundwater table in the off-site source area would further reduce/minimize the volume of contaminant mass in contact with the groundwater and, therefore, reduce the flux of dissolved-phase contaminant mass originating from this area while mass removal via SVE/biological activity was occurring.

  Preliminary review indicates that a property line hydraulic barrier would act synergistically in conjunction with the existing off-site hydraulic barrier, and that the total groundwater extraction rate requirement for the combined operation of both barriers would likely remain within the historical range of approximately 160 gpm.

The use of an additional hydraulic barrier at the property line and its enhancement to the mass reduction in the off-site source area should assist in reducing the overall project time required to attain milestone goals for active remediation and a transition to monitored natural attenuation in the off-site area.

A hydraulic property line barrier is also considered to be the most reliable means to prevent migration of contaminants downgradient of the terminal property boundary. While a pump-and-treat system may be considered to be an ineffective remedial method for the removal of contaminant mass from a source area, in this case its primary objective is to serve as a barrier to contaminant migration and not as a method of remediation.

Selection of an in-situ barrier technology (i.e., ART or other oxygenation strategy) would require a site-specific pilot study to demonstrate whether or not it would be effective as a containment barrier. Even if such an alternative were determined to be feasible, a considerable amount of time would be required to effectively prove-out and design a site-specific process for meeting the project goals. Additionally, evaluating and monitoring the effectiveness of an in-situ barrier technology would be extremely difficult if not impossible under the current off-site conditions. Any groundwater exiting the treatment zone of an in-situ barrier would instantly be in contact with the off-site source material and become re-contaminated, effectively preventing any useful comparison of water quality data obtained from samples collected upgradient of the barrier to those collected downgradient of the barrier. A pilot study for use of an in-situ barrier technology at the property line may be advisable to determine feasibility for future use after the milestone goals for active remedial efforts in the off-site area have been achieved.

- Operate and evaluate the expanded remedial systems (i.e., additional SVE wells and property boundary containment barrier) for a period of three years.

  The operation and effectiveness of the remedial systems will be monitored and evaluated over the initial three years of operation. Evaluation of the treatment system will be performed to review the need for additional measures to enhance the effectiveness of the treatment system progress toward cleanup milestones. This evaluation will be performed and a report describing the results and conclusions will be submitted to the RWQCB on or before June 1, 2009.

6.2 Clean-up Milestones

Milestones for clean-up of the off-site area are listed below:

- Reduce the mass flux of COCs in groundwater within the Mission San Diego Hydrologic sub area proposed for development for municipal use (i.e., downgradient of Transect 2 [Figure 3]) to below the mass flux targets.

The off-site source containment barrier located downgradient of the residual LNAPL is successfully reducing COC mass flux downgradient of the source area to below the mass flux targets. Therefore, we believe that the first remedial objective in the TSO, "Restore water quality in the portion of the Mission San Diego Hydrologic sub area proposed for development by the City of San Diego for municipal use," has been achieved.

- Reduce the COC concentrations in soil gas to below the target concentrations for commercial workers in the off-site area (i.e., parking lot and Stadium areas).

  Based on current land use and associated receptors, there are no indoor workers overlying the off-site LNAPL-affected zone. As described in the Health Risk Assessment, Off-Site Areas Report (Environ and LFR, 2003), COCs present in the soil gas do not currently pose a significant risk to current and future outdoor workers and Stadium visitors.

- Reduce measurable thickness of LNAPL in the off-site area to less than 0.01 foot.

  This milestone will be achieved when the LNAPL thickness in off-site monitoring wells exhibits a thickness of less than 0.01 foot for four consecutive quarterly monitoring events. Historical LNAPL thickness measurements in off-site area monitoring wells indicate an overall reducing trend. It is projected that the reduction of LNAPL thickness to 0.01 foot will be achieved by January 2007.

- Reduce COC concentrations within the downgradient portion of the dissolved-phase plume to levels that result in the mass flux across a transect located at RW-9 to be less than the mass flux target (i.e., less than 5 g/day of MTBE).

  This milestone will be achieved when the total COC mass extracted from RW-9 is reduced to a level such that the COC mass flux across a transect located at RW-9 is less than the mass flux targets for three consecutive monitoring events. This cleanup milestone is based on the time required to capture two pore volumes within the current area of high COC concentration around this extraction well. Based on this criteria, we estimate that extraction of groundwater from well RW-9 will be discontinued by January 2011.

- Reduce COC concentrations within the downgradient portion of the dissolved-phase plume to levels that result in the mass flux across a transect located at RW-8 to be less than the mass flux target (i.e., less than 5 g/day of MTBE).

  This milestone will be achieved when the total COC mass extracted from RW-8 is reduced to a level such that the COC mass flux across a transect located at RW-8 is less than the mass flux targets for three consecutive monitoring events. This cleanup milestone is based on the time required to capture two pore volumes within the current area of high COC concentration in the vicinity of this extraction well, and the implementation milestone for the property boundary containment barrier and anticipated migration time. Based on this criteria, we estimate that the extraction of groundwater from well RW-8 will be discontinued by January 2012.

- Reduce COC concentrations within the off-site residual LNAPL area to levels that enable the COC mass flux in groundwater from this area to be less than the mass flux targets when active off-site remedial activities cease.

  Details regarding the development of time estimates for achieving this milestone are presented in Appendices B through F. Appendix B presents information regarding soil properties in the off-site source area, and Appendix C presents details regarding the estimation of LNAPL and COC mass in the off-site source area. Appendices D, E, and F subsequently make use of the information presented in Appendices B and C to develop estimates of COC depletion estimates from LNAPL in the off-site source area.

  Estimates of the time required to reduce COC mass in the off-site source area such that the mass flux from a hypothetical future water table rise that completely submerges the residual LNAPL soil volume are presented in Appendices D and E for the currently saturated and unsaturated portions of the residual LNAPL soil volume, respectively. Simplified calculations of saturated-zone LNAPL depletion suggest that benzene may persist above mass targets in the saturated zone for anywhere from 50 to 500 years, if LNAPL depletion in the affected soil beneath the current water table occurs primarily through dissolution into groundwater. MTBE is estimated to persist above mass targets in the saturated zone for anywhere from 1.7 to 30 years. Extrapolation of site-specific empirically derived soil-vapor extraction rates suggest that both benzene and MTBE may persist above the mass targets in the unsaturated zone for 1 to 3 years, assuming continued operation of the expanded SVE system.

  Natural attenuation of the source zone may reduce these time estimates, whereas mass transfer limitations from bypassed LNAPL and low-permeability soils may increase these time estimates (Appendix F). In addition, site data indicate that natural attenuation significantly reduces the flux of benzene within a few hundred feet downgradient from the source zone. Therefore, the benzene flux target may be achieved more rapidly at a transect located a short distance downgradient of the source zone, compared to a transect adjacent to or within the source zone.

  The COC mass reduction targets in the off-site area, as developed in Appendix D, will be attained when observed groundwater and soil-vapor concentrations in the off-site source area are less than the groundwater and soil vapor targets as developed in Appendices D and E, respectively, for three consecutive monitoring events. Once concentration targets have been met, active remedial measures in the off-site area may be discontinued, coupled with continued groundwater monitoring to verify attainment of flux targets. It is estimated that the concentration and flux targets milestone will be attained sometime between 2015 and 2034.

6.3 Clean-Up Goals

The second remedial goal stated in the TSO, "Clean up all off-site pollution," requires attainment of the applicable Water Quality Objectives, including narrative objectives in all off-site groundwater, consistent with the designated beneficial uses of groundwater and surface water for the Mission San Diego Hydrologic Sub Area, as identified in the Basin Plan (CRWQCB 1994).

The Basin Plan states that groundwater in the Mission San Diego Hydrologic Sub Area is designated for use as Municipal or Domestic Supply. For the COCs (BTEX and fuel oxygenates), water quality objectives for Municipal and Domestic Supply are typically more stringent than other potential supply uses such as Agricultural Supply or Industrial Service Supply and Process Supply (Marshack 2003). To be conservative, only water quality objectives for Municipal and Domestic Supply will be considered for development of clean-up goals for the off-site area. In addition, the Basin Plan states "Waters shall not contain taste or odor producing substances at concentrations which cause a nuisance or adversely affect beneficial uses." Therefore, for the COCs, the applicable water quality objectives for groundwater would include drinking water standards, including primary Maximum Contaminant Levels (MCLs) and secondary MCLs, and taste-and-odor thresholds for chemicals with no established secondary MCL.

6.3.1 Numerical Clean-up Goals

The Basin Plan (CRWQCBSDR 1994) does not contain specific numerical criteria for MTBE in groundwater. Since the Basin Plan was last modified, California has adopted a primary drinking water MCL for MTBE of 13 µg/l, based on health concerns, and a secondary MCL of 5 µg/l, based on aesthetic (odor) criteria. These are proposed as the applicable water quality objectives for MTBE in groundwater, to be met before potable beneficial uses are restored. Therefore, the most stringent water quality objective for MTBE in groundwater at the site is proposed to be 5 µg/l.

No primary or secondary MCLs have been promulgated for TBA. The California Department of Health Services (DHS) has identified an action level of 12 µg/l for TBA. Action levels are health-based advisory levels established by DHS for chemicals in drinking water that lack MCLs (Cal/EPA 2002). Therefore, the most stringent water quality objective for TBA in groundwater at the site is proposed to be 12 µg/l.

The California primary MCLs for BTEX constituents are 1 µg/l for benzene, 150 µg/l for toluene, 300 µg/l for ethylbenzene, and 1,750 µg/l for xylenes. The primary MCL for Ethylene Dibromide (EDB) is 0.05 µg/l. Federal secondary MCLs, based on taste and odor considerations for drinking water, are 40 µg/l for toluene, 30 µg/l for ethylbenzene, and 20 µg/l for xylenes. Benzene has no established State or Federal secondary MCL; however, a taste and odor threshold of 170 µg/l has been identified for benzene in drinking water (Amoore and Hautala 1983). Therefore, the most stringent water quality objective for benzene in groundwater at the site is proposed to be 1 µg/l.

Note that background concentrations have not been proposed as clean-up goals for this site. State Water Resources Control Board Resolution 92-49 states that clean-up levels may be less stringent than background if they are consistent with the maximum benefit to the people of the State, do not unreasonably affect present and anticipated beneficial uses, and do not result in water quality less than that prescribed in Water Quality Control Plans and Policies (SWRCB 1996).

6.3.2 Narrative Clean-up Goals

In addition to numerical water quality objectives, the Basin Plan includes a narrative objective to achieve groundwater that exhibits “absence of nuisance and toxicity.” The “nuisance” provision of this narrative objective is addressed by the taste and odor criteria discussed in the preceding text. In order to address the “absence of toxicity” provision of this narrative objective, site-specific goals have been developed in the form of target concentrations (RBTCs) for groundwater and soil gas in the off-site area (Environ and LFR 2004). The Health Risk Assessment, Off-Site Areas Report (Environ and LFR 2003) indicated that the only potentially complete exposure pathways that currently exist at the site are those related to soil-vapor migration to indoor and outdoor air. RBTCs established as cleanup goals for the off-site area are based on the current land use (CRWQCBSDR 2002 and 2004). RBTCs for groundwater and soil gas are based on commercial worker exposure for current land uses. Table 2 summarizes the proposed RBTCs. None of the proposed RBTCs are currently exceeded near any current receptor.

6.3.3 Estimated Timeframes for Achieving Clean-up Goals

Calculations of the rate of LNAPL depletion in the saturated zone and unsaturated zone (presented in Appendices D and E, respectively) provide insight regarding the expected timeframe for attainment of water quality objectives. Appendices D and E focus on the timeframes for attainment of implementation milestones (i.e., mass flux targets), rather than on the attainment of clean-up goals (i.e., water quality objectives) at every subsurface location. Because clean-up goals are more stringent than implementation milestones, the timeframes for attainment of clean-up goals are likely to be significantly longer than the timeframes for attainment of implementation milestones.

Timeframes for achieving clean-up goals are highly uncertain and are potentially very long. In 1998, the State Water Resources Control Board clarified its policy on timeframes to achieve water quality objectives in a case closure appeal often called the Walker Decision. Specifically, it states “Resolution 92-49 does not require…that the requisite level of water quality be met at the time of site closure. Even if the requisite level of water quality has not yet been attained, a site may be closed if the level will be attained within a reasonable period” (SWRQCB 1998). For the off-site area near the Mission Valley Terminal, an extended timeframe to achieve final clean-up goals is reasonable, provided that the remnant LNAPL-affected area and plume demonstrate response to cleanup efforts, and beneficial uses are not being impaired.

6.3.4 Uncertainties in Timeframe Estimates

Development of the timeframe estimates for attainment of implementation milestones is based on available and appropriate data, and analytical and numerical methods consistent with the site conceptual model and appropriate for the level of characterization of the off-site area. However, uncertainty still exists with regard to this data, the application of simplified interpretive and predictive methods, and the site conceptual model. Within the scope of the data and methods used, an attempt has been made to characterize the uncertainty of the resulting predictions. Confidence limits of 97.5 percent have been evaluated where applicable, and other conservative limits and assumptions have been used where error analysis is not feasible. Through the use of these limits and assumptions, conservative estimates are presented within a reasonable range based on the data. Predictions using higher degrees of conservatism are possible, but these higher degrees of conservatism would result in what may be regarded as speculative results and unreasonably long timeframes. In addition, the evaluation and use of means, fitting parameters, and particularly confidence limits assumes a degree of reliability (e.g., representativeness and ergodicity) in the data used as bases for the evaluation(s). If this is not the case (for example, if there is some major, unrecognized hydrogeologic feature or process that will negatively impact mass reduction in the off-site area), then the selected timeframe estimates could be in significant error.

A process that has not been included in the timeframe estimates is diffusion-limited mass transfer from low-permeability horizons, in which some of the residual LNAPL appears to be trapped (i.e., immobile). Should these horizons be of sufficiently low permeability such that diffusive mass transfer is dominant over advective mass transfer, the timeframes to meet the mass-flux targets may be substantially longer. Calculations presented in Appendix F suggest that diffusion-limited mass transfer may prolong the timeframes to meet mass-flux targets by up to 140 years.

7.0 UPDATE TO CONCEPTUAL RISK MANAGEMENT/ CONTINGENCY PLAN

This section presents an update to the conceptual risk management plan (the “management plan”) that was originally presented in the off-site health risk assessment report dated August 4, 2003 (Environ and LFR 2003), along with details regarding how contingency actions would be triggered and what the actions would be. The purpose of the management plan is to effectively and efficiently contain source areas and remediate the hydrocarbon plume emanating from the Terminal through the augmentation of existing remedial systems and development of innovative strategies. Since publication of the original management plan, the off-site source area has been effectively contained and attenuation of the dissolved-phase plume has been accelerated through enhancements to the previously existing groundwater extraction system. Additionally, remediation of the off-site source area has been improved via enhanced hydrocarbon COC mass extraction resulting from an initial expansion and optimization of the SVE system, and will be further improved by completion of a second phase of expansion scheduled to become operational in early 2004.

The following are the three main elements to the original management plan presented in the August 2003 health risk assessment report:

- Residual LNAPL (Dissolved Plume Source Area) Containment
- Dissolved Hydrocarbon Plume Management
- LNAPL Remediation (through risk reduction via hydrocarbon COC reduction and/or pathway elimination)

Each of these elements is discussed further below.

7.1 Residual LNAPL (Dissolved Plume Source Area) Containment

The purpose of the source area containment is to hydraulically contain (reduce existing COC mass flux to acceptable levels that will allow future beneficial use of the downgradient aquifer) groundwater contaminants emanating from the LNAPL zone with a goal of long-term complete containment. The objective of COC mass flux reduction is to allow for dissipation of the downgradient MTBE plume within a reasonable time frame that will allow for the beneficial use of the aquifer while protecting existing and future receptors. LFR believes that the completed enhancements to the groundwater extraction system have already achieved the desired objective of allowing for beneficial use of the aquifer downgradient of the containment system, based on the following:

- Results of the completed mass flux evaluation activities (LFR 2003b and 2003d)
- State Water Resources Control Board Order No. WQO 2003-0011-UST (SWRQB 2003)
- Information regarding anticipated locations for the future placement of water supply wells in Mission Valley, as presented in the San Diego River System Conceptual Groundwater Management Plan (CH_2MHill 2003)

Additionally, use of the aquifer for municipal drinking water supply is currently not anticipated prior to the year 2010, allowing for additional attenuation of the MTBE plume prior to the use of the aquifer for municipal water supply.

The original management plan included the following activities that are detailed further in the TSO: enhanced preferential pathway evaluation (TSO Tasks A.1 and A.3); a performance evaluation of the existing soil vapor extraction system (TSO Tasks C.1 and C.3); a performance evaluation of the existing groundwater extraction system (TSO Tasks C.2 and C.3); groundwater and COC fate and transport modeling (TSO Tasks B.1 and B.2); augmentation of the existing soil-vapor extraction and groundwater pump-and-treat system, as warranted (TSO Tasks C.4 and C.5); and a performance evaluation of the augmented systems (TSO Task C.5). Specific proposed steps to obtain source area containment were presented as follows:

1. Evaluation of existing pump-and-treat system (TSO Tasks C.2 and C.3)
2. Initialize interim pump-and-treat upgrade
3. Phase IA enhanced core plume characterization (on-site)
4. Phase IB enhanced core plume characterization (off-site)
5. Enhanced hydraulic evaluation and modeling (TSO Tasks B.1 and B.2)
6. Enhanced containment system design (TSO Tasks C.4 and C.5)
7. Installation of enhanced containment system (if required, TSO Tasks C.4 and C.5)
8. System performance monitoring (TSO Task C.5)
9. Ongoing Risk Analyses
10. Completion of Remedial Alternative Analyses for on- and off-site areas

As described in Sections 2 through 5 of this report, Item Nos. 1, 2, and 5 through 9, above, have been completed in accordance with the requirements of the TSO. Item Nos. 3 and 4 have also been completed as reported in LFR's Additional LNAPL Distribution and Lithologic Characterization Report (LFR 2003e). As described in Section 5.2, additional risk analysis for the on-site area is currently in progress and scheduled for completion in early to mid 2004, as is an evaluation of innovative technologies for off-site source reduction. A Supplemental Health Risk Assessment for the off-site area was recently completed (Environ and LFR 2004). A remedial alternatives analysis for the on-site area will be developed, as necessary, based on the pending results of the on-site risk assessment.

7.2 Dissolved Hydrocarbon Plume Remediation

The purpose of the dissolved hydrocarbon plume remediation is to restore the beneficial use of the aquifer within a reasonable time frame while protecting existing and potential future receptors. As previously stated, LFR believes that this objective has already been accomplished via augmentation of the groundwater extraction system. Hydraulic capture of the central core of the off-site dissolved-phase plume and containment of the source area is allowing the distal plume to dissipate while protecting potential downgradient receptors. Implementation of this remediation has included additional characterization, consideration of innovative technologies, and plume monitoring. Specific proposed steps to obtain dissolved hydrocarbon plume remediation were presented in the original management plan, as follows:

1. Additional plume characterization
2. Receptor evaluation (TSO Tasks A.1 and A.3)

3. Soil/water samples for evidence of MTBE degraders
4. Develop an information tracking system for long-term management (e.g., Terradex)
5. Microcosm studies for MTBE degraders
6. Hydraulic evaluation and modeling (TSO Tasks B.1 and B.2)
7. Feasibility Study
8. Implement interim corrective action

As described in Sections 2 through 5 of this report, four of the above items (Nos. 1, 2, 6, and 8) have been completed in accordance with the requirements of the TSO. However, the corrective actions that have been implemented to date are not necessarily considered to be interim. Evaluation of indicators of biological degradation in groundwater samples (Item No. 3) is an ongoing component of quarterly monitoring activities, and a microcosm study for aerobic MTBE degraders (Item Nos. 3 and 5) is in progress at the University of California, Davis. Results from the microcosm study are anticipated during the first half of 2004. The need to develop an information tracking system for long-term management (Item No. 4) will continue to be periodically evaluated as remediation of the off-site area progresses.

7.3 LNAPL Remediation (through risk reduction via hydrocarbon COC reduction and/or pathway elimination)

The purpose of the off-site residual LNAPL remediation is to evaluate, design, and implement a remediation approach that is technically practical in reducing COC mass in the LNAPL core plume. The goal of this remediation is to evaluate the effectiveness and efficiency in reducing COC and residual LNAPL mass to a level that results in an acceptable COC mass flux while allowing beneficial use of the downgradient aquifer and maintaining an acceptable level of risk to users of the QualComm Stadium property. To this end, technologies able to achieve the required LNAPL remediation are being evaluated and pilot tested. The selected remedial approach is being implemented and, following completion, the only necessary containment system will be located at the downgradient end of the Terminal for the purpose of long-term containment. The specific steps that were proposed in the original management plan to evaluate LNAPL remediation were:

1. Enhanced core plume characterization of residual LNAPL (off-site)
2. LNAPL modeling (determine necessary LNAPL reduction – e.g., API LNAST model)
3. Feasibility evaluation
4. Pilot tests
5. Implement preferred alternative
6. Relocate containment system to Terminal after off-site residual LNAPL remediation is complete

Item No. 1, above, has been completed as reported in LFR's Additional LNAPL Distribution and Lithologic Characterization Report (LFR 2003e). Item Nos. 2 through 6 are discussed in Section 6, above.

In addition to COC and LNAPL mass reduction, and in the case that LNAPL is technically infeasible or cost prohibitive to remediate, pathway elimination will be considered. Pathway elimination is commonly addressed through the use of institutional and engineering controls. The remedial alternative analyses will consider vapor barriers, capping, and other engineering controls. Institutional controls will also be evaluated to prevent unacceptable use or uses that may cause an unacceptable risk. These types of controls can come in the form of required health and safety plan (i.e., for deep excavation work), deed restrictions (i.e., to prevent agricultural or residential use) or groundwater use restrictions (i.e., shallow water withdrawal). All such restrictions would be in place until acceptable risk levels are achieved or beneficial uses of the aquifer are attained.

7.4 Proposed Schedule

This document represents the next step in the ongoing implementation of the management plan. Specific future actions proposed or contemplated within this report (e.g., further modifications to or expansions of remedial actions or evaluations of remedial performance) may require that additional work plans be submitted and approved before implementation.

7.5. Contingency Triggers and Contingency Measures

Contingency activities are planned in order to facilitate progress toward remediation milestones and clean-up goals in the event that the predicted progress is not being achieved. It is anticipated that upon final selection of treatment technologies proposed in Sections 6.0 and 6.1, progress metrics will be developed for the treatment technologies in order to determine if the cleanup is effective and on schedule to meet the proposed cleanup milestones. If monitoring of the expanded treatment system indicates significant variation from the predicted progress, which may result in not achieving the cleanup milestones, contingency activities will be performed to further enhance the effectiveness of the treatment system.

Example scenarios that would trigger a contingency implementation activity include the following:

- a trend of increasing groundwater COC mass flux downgradient of the off-site residual LNAPL area, if the trend indicates that exceeding COC mass flux targets is likely
- a trend of increasing LNAPL thickness greater than 0.01 foot in more than two monitoring wells for three consecutive quarterly monitoring events

- a trend of increasing soil-gas concentrations indicating that exceeding risk-based soil-gas targets is likely
- progress toward reduction of COC concentrations within the off-site residual LNAPL area is insufficient to meet the proposed cleanup milestone dates

Examples of contingency actions include the following:

- Enhance the hydraulic containment barrier downgradient of the off-site residual LNAPL area.

  Example alternate measures include installation of additional groundwater extraction wells as part of the hydraulic containment barrier, and wellhead treatment (if a supply well is operating and may become impacted).

- Enhance mobile LNAPL recovery actions in the off-site residual LNAPL area.

  Mobile LNAPL recovery alternatives will be evaluated and an appropriate solution (e.g., bailing, dual-phase extraction, passive-collection methods) will be implemented.

- Treatment system enhancement technologies feasibility evaluation.

  If progress toward cleanup milestones is determined to be significantly less than predicted, evaluation of enhancement technologies will be performed and a report describing the results and conclusions will be submitted to the RWQCB within one year from the date that the contingency activity was triggered.

- Treatment system enhancement.

  Based on the results of the enhancement technologies feasibility evaluation, an appropriate treatment system enhancement technology will be selected and installed and operational within one year after review and approval of the evaluation of treatment system enhancement technologies.

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